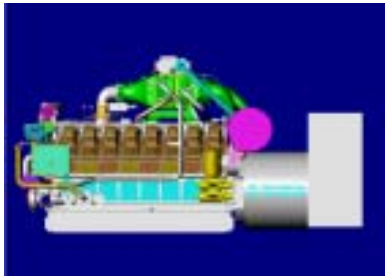
U.S. Department of Energy's Advanced Natural Gas Reciprocating Engine Program

Debbie Haught

DER Peer Review

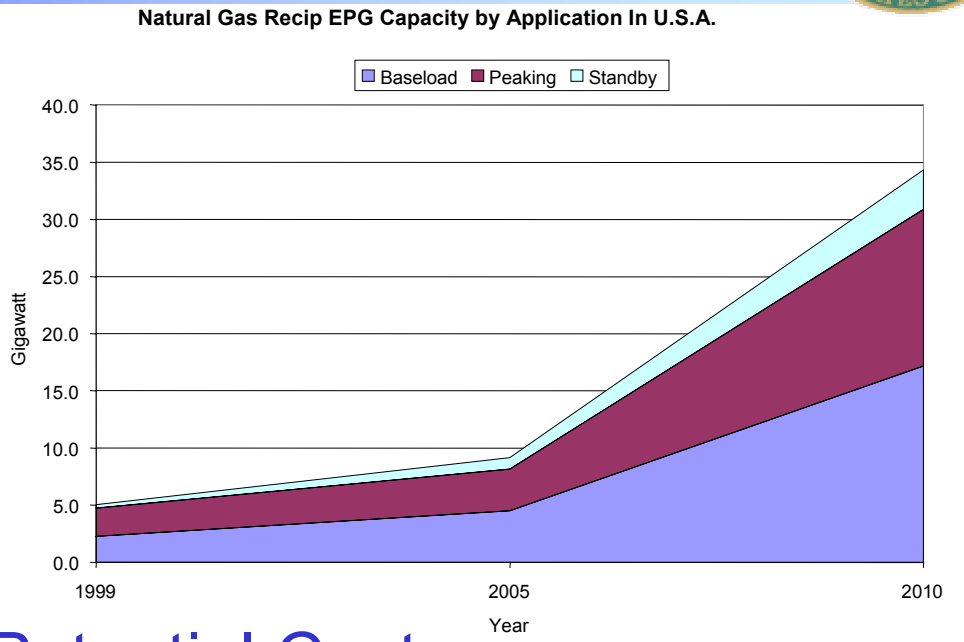
November 29, 2001



Key Markets

- Base load electrical power generation
- Combined heat and power applications
- Peak shaving applications
- Grid support in congested areas
- Standby support

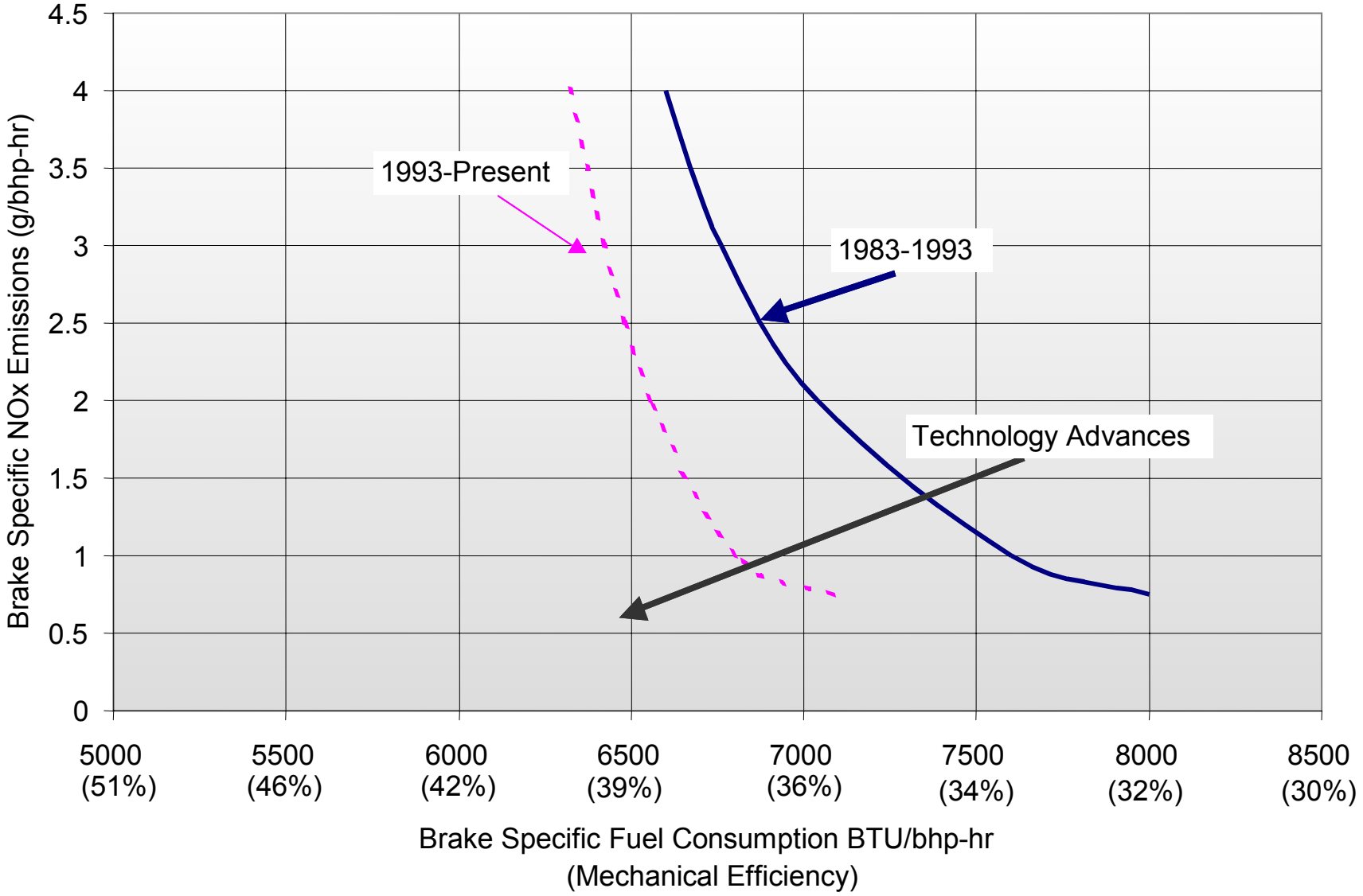
More detailed study of markets is underway by EEA



Potential Customers:

- Shopping Malls
- Hospitals
- Large Apartment Complexes
- Municipalities
- Small Industrial Parks
- Hotels

NO_x Emissions vs. Fuel Consumption



Collaborative Advanced Engine Program

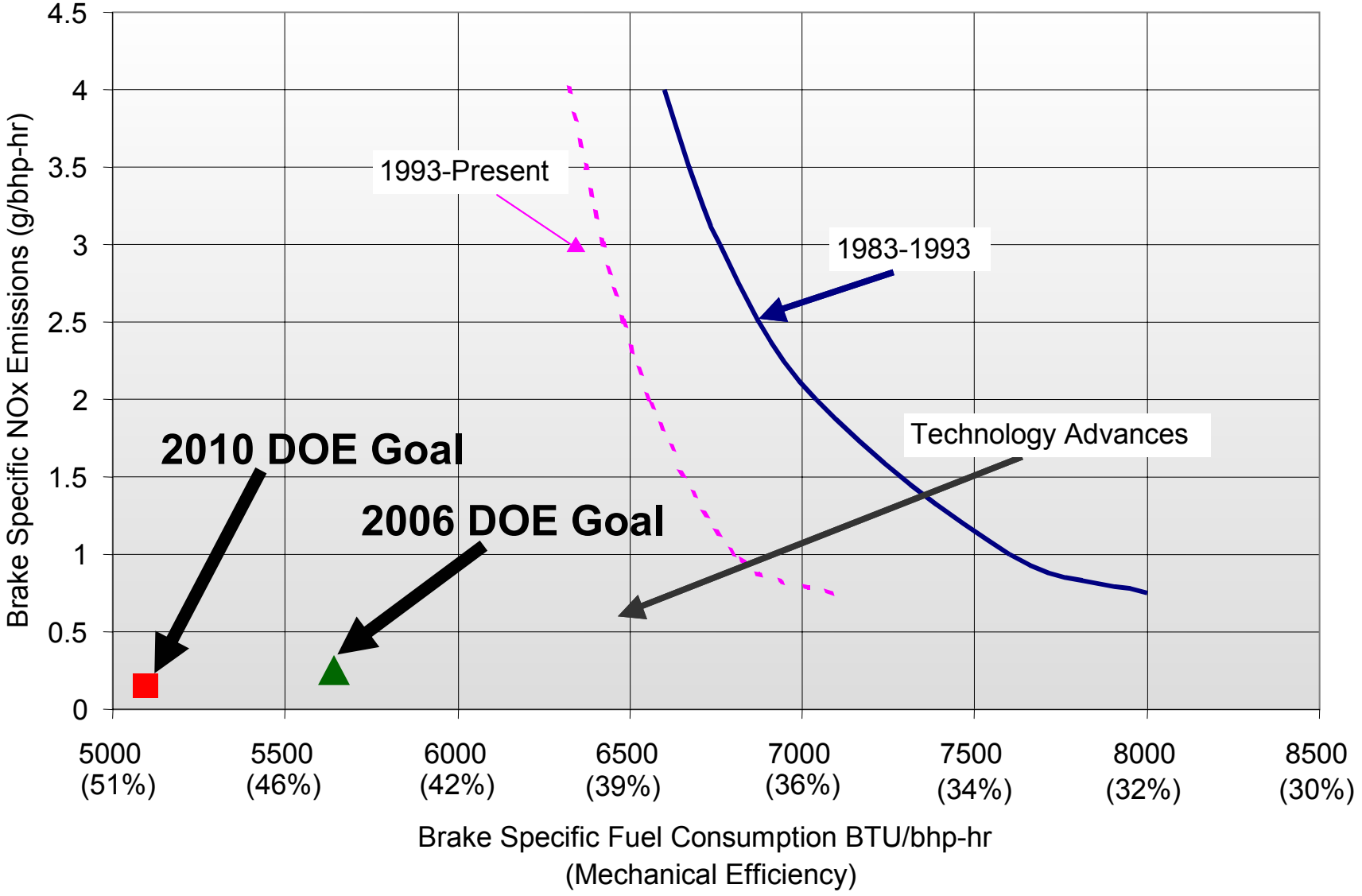
- 1999 - Joined SWRI study commissioned by ARES consortium to determine advanced technology roadmap
- Fall 1999 - Conducted DOE workshop to define reciprocating engine program goal and objectives
- Currently 7-year program (2000-2006)
  - Initial program funding in FY2000

DOE Program Goal

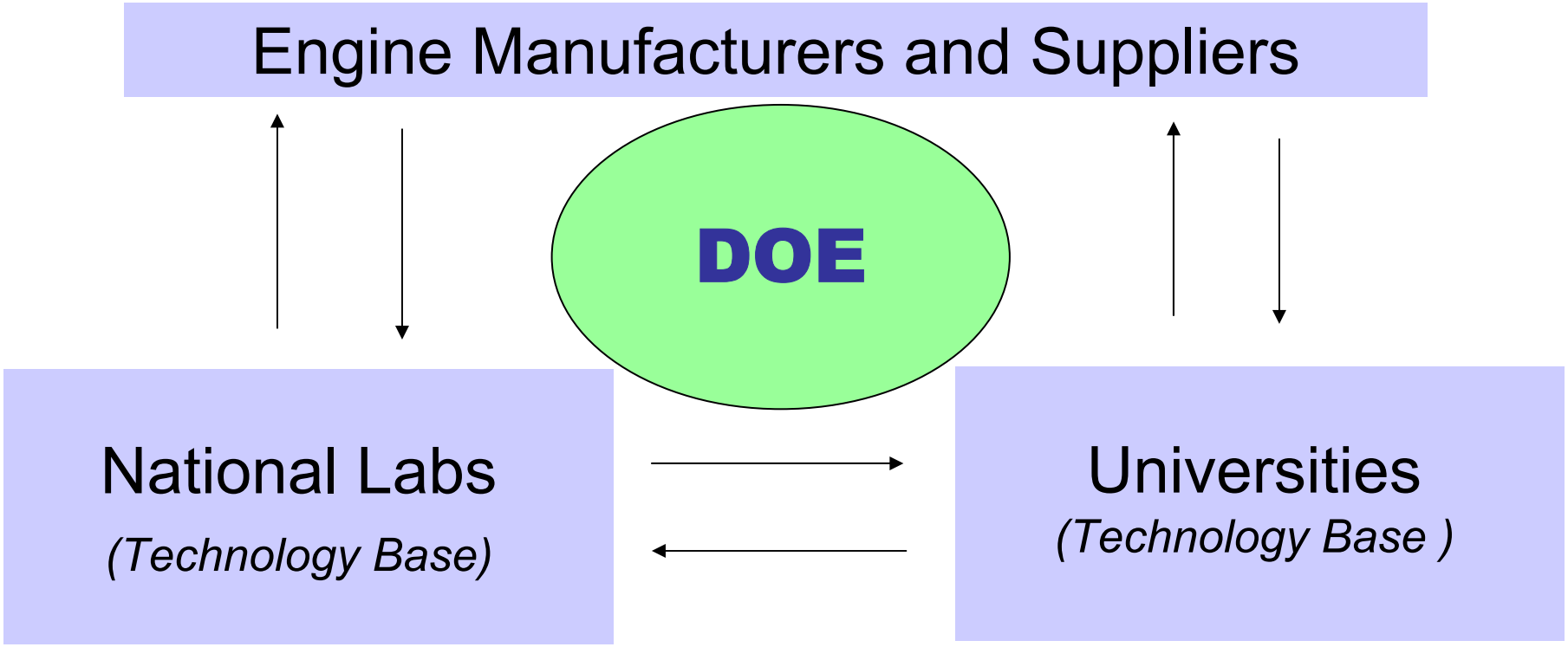
A Commercial Engine by 2010 with:

- **High Efficiency -** Fuel-to-electricity conversion efficiency of at least 50%
- **Environmental Superiority -** NO_x < 0.1 g/hp-hr (natural gas)
- **Reduced Cost of Power –** Energy costs, including O&M, at least 10% less than current state-of-the-art engines
- **Fuel Flexibility –** Adaptable to future firing with dual fuel capabilities, include further adaptation to hydrogen
- **Reliability and Maintainability –** Equivalent to current state-of-the-art engines

NO_x Emissions vs. Fuel Consumption

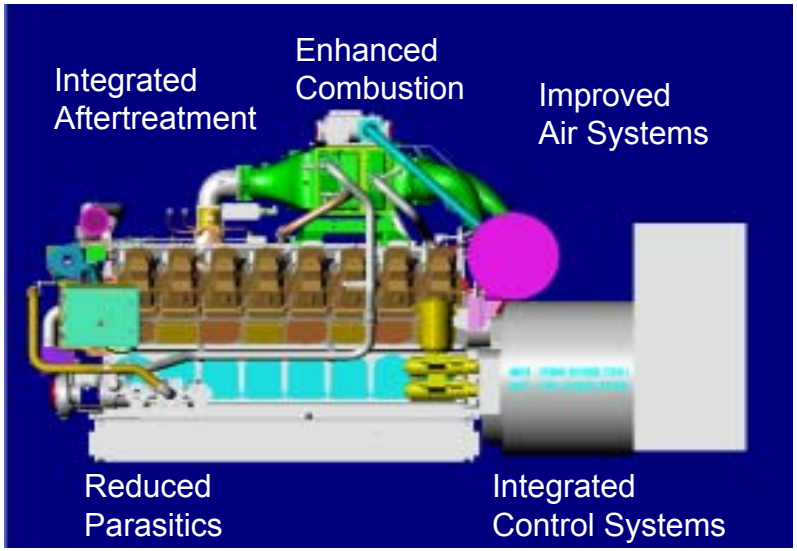


DOE's Strategy is Based on Partnerships



- **Leverage limited resources**
- **Reduce financial and technical risks**
- **Competitive solicitations**

Program Timeline



- DOE Workshop
- Industry Solicitation
- National Laboratory Call
- Awards to Industry Partners
- University Solicitation
- Awards to Universities

1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010

Concepts

Development

Demonstrations

Commercialization

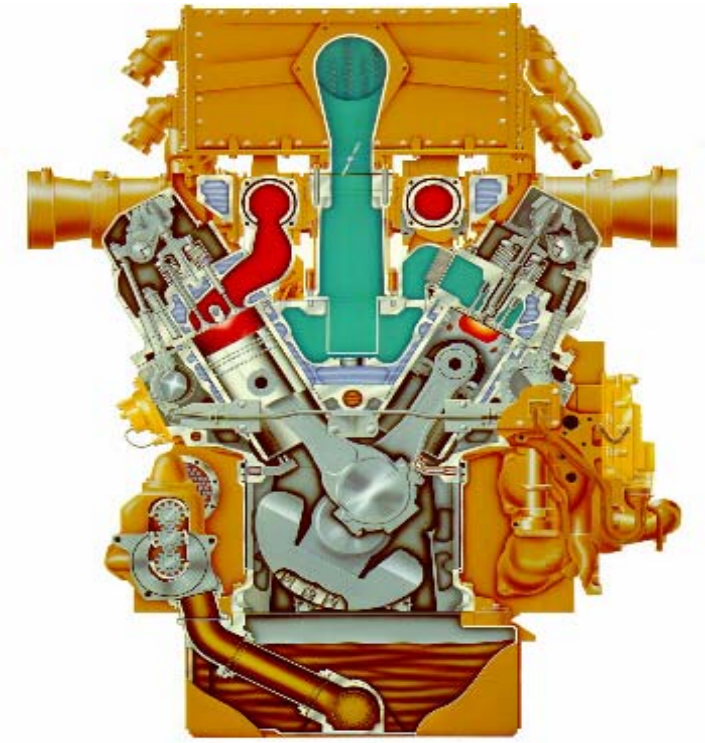
DOE Commitment

Industry Awards

- **Focused on research, development, and testing of advanced natural gas reciprocating engines**
- **Three awards totaling at least $15.0 million over 5 years:**
  - Caterpillar, Inc. (Lafayette, Ind.)
  - Cummins Engine Company, Inc. (Columbus, Ind.)
  - Waukesha Engine Division, Dresser Inc. (Waukesha, Wis.)
- **Average cost share over program 50% - staged over development: 30%, 45%, 60%**
- **Projects managed by Chicago Operations Office**

Caterpillar ARES Program

- **Vision: Develop and commercialize a 50% efficient natural gas fueled reciprocating engine system with a 95% reduction in NOx emissions with no increase in first cost by the year 2010.**
- **Size Range: Overall 0.5MW - 7.0MW, Initial Focus 2MW - 4MW**
- **Partners: Oak Ridge National Lab, Southwest Research Institute, Woodward Controls, Modine Heat Exchangers**

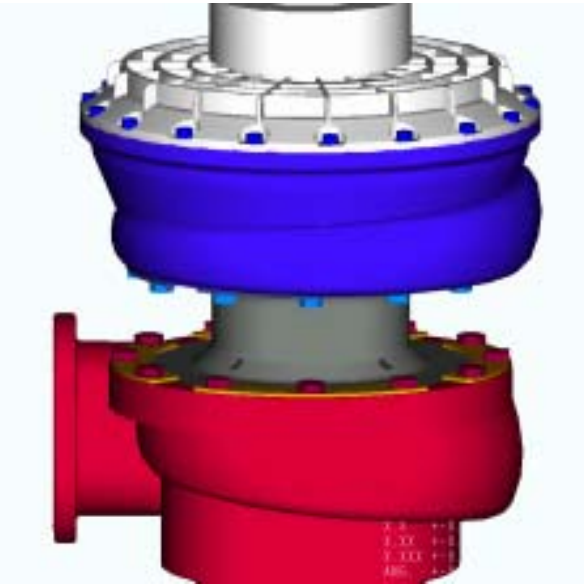


Caterpillar G3500 series gas engine cross-section

GAS ENGINES

Phase I

- COMBUSTION
  - Cat Low-Loss Combustion System
  - 50% Power Density Increase
- AIR SYSTEM
  - Innovative, 70% Efficient Turbochargers
- CATALYSTS AND CONTROLS
  - Combined for Success, 0.1g NOx capable
- **2004 Field Demonstrations - 45% thermal efficiency / 0.25g NOx**



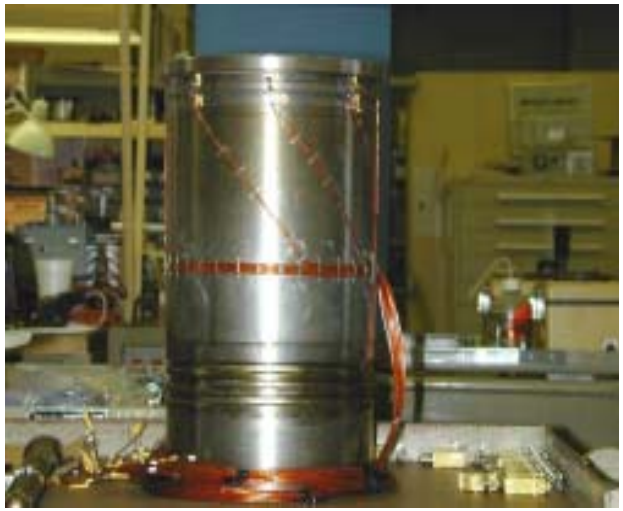
Caterpillar HEAT™ Turbocharger Design

CAT® GAS ENGINES

	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Efficiency Goals	40% State of the Art			Phase I 45%			Phase II 47%			Phase III 50%

Phase II & III

PHASE II & III PACKAGES



- **OPTIMIZE PHASE I**
  - Concepts
    - Advanced Combustion Cycle
    - Variable Valve Timing Capability
    - Electronic Turbocompounding Capability
- **2007 Field Demonstrations - 47% thermal efficiency / 0.1g NOx**
- **2010 Field Demonstrations - 50% thermal efficiency / <0.1g NOx**

CAT® GAS ENGINES

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Program Progress

- HEAT Turbocharger Components Designed and Procurement Underway
- New Platform Analysis Completed, Designs Underway
- Single Cylinder Engine Tests Planned Mid-2002
- Cycle Simulations Underway to Validate New Combustion Systems
- Long Range Reformed Fuel and HCCI combustion Tests Underway

GAS ENGINES

Cummins ARES Program

- **Overall Approach: Implement ARES Technology in Next Generation Natural Gas Quantum Series Products from 0.3 - 2.0 MW:**
  - 44% Brake Efficiencies
  - 0.1 gm NO_x/bhp-hr
  - 2005 First Product Launch
  - 2008 Second Round of Improvements, 47% Brake Efficiency

- **Partners; Westport Innovations, Colorado State University, Ricardo, ORNL, Southern California Gas Company, NICOR Energy Solutions**
- **Technologies:**
  - Combustion
  - Air Handling
  - Parasitics
  - Power Recovery
  - Next Generation After-treatment

Technical Approach

- **Select Best Combustion System**
  - Address; Efficiency, Reliability, Durability, Emissions, Cost
  - Extend Lean Burn Capability
  - Advanced Spark Ignition & Two Alternative Combustion Systems
- **Reduce Parasitic Power; Mechanical & Support System**
  - Piston, Ring & Liner Tribology
  - Optimize/Minimize Sub-systems Power Requirement
- **Improve Air Delivery & Energy Recovery**
  - Improve Efficiency & Utilization of Exhaust Energy
  - Turbomachinery, Ports & Valves, Intake & Exhaust Manifolds
- **Optimal Use of After-treatment**
  - Apply Next Generation of Exhaust After-treatment

Program Progress

- Prototype westport fuel system exceeding performance and emissions expectations
- Three combustion/ignition alternatives, and air handling improvements projects are underway
- Fast burn spark ignition combustion chamber selected for further development

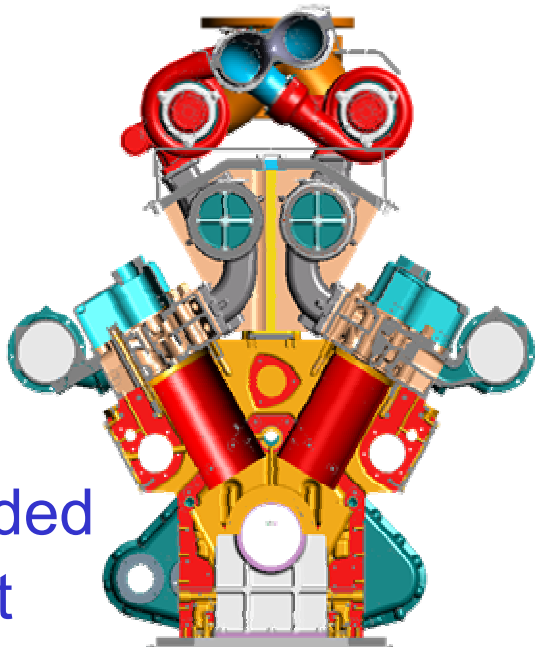
Waukesha ARES Program

- **Overall Program Approach:**
  - Further advance ARES technology findings
  - Demonstrate technology at customer sites
- **Partners: TRW, Winsert, Borg Warner, NICOR, MIT & CSU university**
- **Product: Engine/generator power plant (Modulator™) with high operating efficiency and low exhaust emissions:**
  - 2004: 0.25 NOx, 45% BTE
  - 2007: 0.10 NOx, 47% BTE
  - 2010: 0.10 NOx, 50% BTE

APG2000 Modulator™

Technical Path

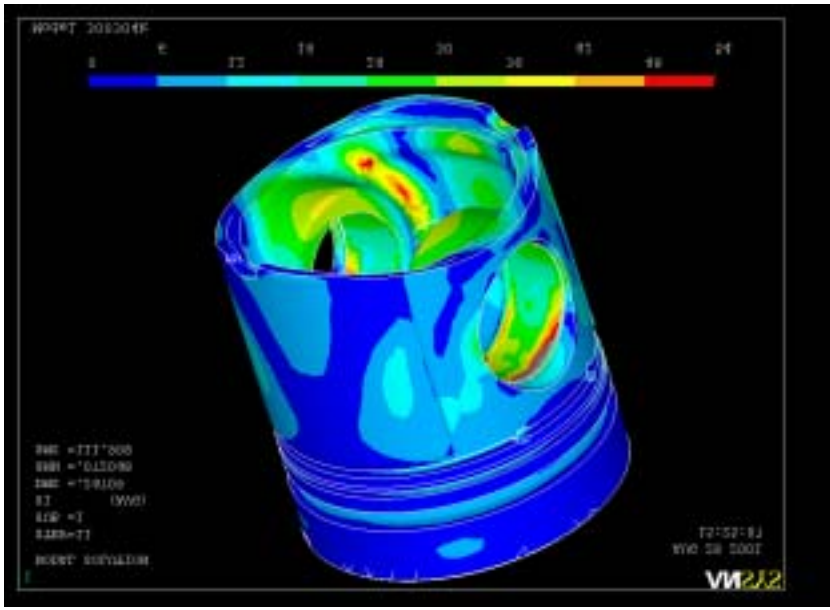
- **Efficiency & emissions**
  - Assess multiple combustion systems
  - Evaluate four ignition system technologies
  - Conduct parasitic loss analysis & reduce friction
  - Select optimum catalyst technology
- **Reliability & cost**
  - Assess engine platform & upgrade as needed
  - Cylinder head & power cylinder state-of-art designs
  - Integrate system controls into state-of-art hardware
- **Lab & customer site endurance testing of demonstrated technology**



DRESSER Waukesha

1st Quarter Progress

- Combustion system modeling underway
- Engines being readied for test programs
- Three of four ignition systems are in the testing phase



- Design analysis of critical engine components is underway
- Control system strategies identified & design work started

National Laboratory Projects

- **Focused on pre-competitive research activities that could have a significant impact in achieving the program goals**
- **Industry defined the topics for solicitation**
  - Environmental
  - Sensors and Controls
  - Knock Mitigation
  - Advanced Combustion
  - Ignition Systems
  - Tribology/Friction Reduction
  - Materials Research
- **Selected projects involving four national laboratories at $3.0 million over 3 years**

National Laboratory Projects

- Argonne – Real Time Sensors for Combustion and Emission Control
- National Energy Technology Laboratory – Rapid Compression Machine for Knock Studies
- Oak Ridge – Development of Ultra Lean Burn Natural Gas Engine
- Sandia – Rapid Combustion Linear Electric Generator

University Research Program

- University research projects focused on innovative/breakthrough technologies to address:
  - Ignition systems
  - Friction reduction
- 7 awards announced September 2000 - $4.6 million over 3 years
- 20% cost share
- Project managed by NETL

Seven University Selections Made

Selection for Negotiation of Award

Applicant	Principal Investigator	Months	Project Title/Brief Description
Colorado State University collaborating with Waukesha Engine Dresser, Inc. and Woodward Governor Company	Dr. Bryan Willson 970-490-1418 bryan@engr.colostate.edu	24	*"Fundamental Studies of Ignition Processes in Large Natural Gas Engines Using Laser Spark Ignition"* Will use an existing laser ignition source to create data that will enhance the basic understanding of laser ignition, support related modeling efforts and demonstrate laser ignition as an effective, long-life ignition technique.
Massachusetts Institute of Technology collaborating with Waukesha Engine Dresser, Inc. and Colorado State University	Dr. Victor Wong 617-253-5231 wwong@mit.edu	24	*"Low Engine Friction Technology for Advanced Natural Gas Reciprocating Engines"* Will develop and use computer models to study lubrication conditions in ANGRE engines to develop concepts that reduce friction. Concepts stemming from the analyses will be tested in an actual ANGRE engine.
Michigan Technological University	Dr. Duane L. Abata 906-487-2151 duane@mtu.edu	24	*"Ignition Improvement of Lean Natural Gas Mixtures"* Will develop an on-board dimethyl ether reactor that creates DME from natural gas that is then used for pilot injection.
Purdue University with Caterpillar-Lafayette	Prof. Farshid Sadeghi 765-494-5719 sadeghi@ecn.purdue.edu	36	*"Advanced Natural Gas Reciprocating Engine: Parasitic Loss Control through Surface Modification"* Will develop several models to analyze the effects of patterned surface features on friction and lubrication conditions at an engine's piston ring cylinder liner. A bench-scale test will be designed to further investigate this area of research and to develop one comprehensive computer model that will design and analyze surface patterns.
University of Southern California collaborating with GEC Engineering Corporation	Prof. Paul D. Ronney 213-740-0490 ronney@usc.edu	36	*"Corona Discharge Ignition for Advanced Stationary Natural Gas Engines"* Will test corona discharge ignition in an effort to lower nitrogen oxides emissions without compromising thermal efficiency or, in one case, increasing thermal efficiency. The project will analyze leaner fuel mixtures, water injection and will minimize turbulence in engines by redesigning the intake port and piston shape.
University of Texas at Austin collaborating with Southwest Research Institute and John Crane Packing Company **(AWARDED)**	Prof. Ron Matthews 512-471-3108 rdmatt@mail.utexas.edu	36	*"Reduced Engine Friction and Wear"* Plans to rotate an engine's cylinder liners to reduce friction between the liners and piston rings and develop a model to not only enhance this concept, but to improve the design of piston assemblies as well.
University of Texas at Austin **(AWARDED)**	Prof. Ron Matthews 512-471-3108 rdmatt@mail.utexas.edu	36	*"Railplug Ignition System for Enhancing Engine Performance and Reduced Maintenance"* Will develop and test railplugs and driver-electronics for large-bore natural gas engines, and create an advanced 3-dimensional model to improve ignition-system designs. The model and the university's existing railplug model will be combined.

Examples of Program Coordination

External Coordination

- SWRI ARES consortium
- States (CEC, NYSERDA)
  - CEC ARICE program
- EPRI

Internal DOE

- Integrated Energy Systems (DER)
- CHP (DER)
- Interconnection (DER)
- Hydrogen (OPT)
- University program (FE/NETL)
- Transportation (OTT)

Summary

- Advanced natural gas reciprocating engines will play an important role in current and emerging DER markets
- Key technology challenges need to be overcome to meet aggressive program goals in efficiency, emissions and first cost
- Public/private partnerships with the reciprocating engine community have been established to meet joint program goals
- ARES technology will provide public benefits of improved energy efficiency and reduced emissions

For Additional Information

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